AUTOMATIC REGISTRATION OF INTRA-MODALITY MEDICAL
VOLUME IMAGES USING AFFINE TRANSFORMATION

The present invention relates to the diagnostic imaging arts. It finds particular application in conjunction with CT oncological studies of the lungs and will be described with particular reference thereto. However, it is to be appreciated that the present invention is applicable to a wide range of diagnostic imaging modalities and to the study of a variety of organs for a variety of reasons.

When a patient is undergoing treatment for lung cancer, the lungs are periodically re-inspected, such as with a CT scanner. The oncologist compares the current images from the CT scanner with the images of the subject that were taken at an earlier time. Based on this comparison, the oncologist can determine the rate of progression of the disease or whether it is in remission.

Typically, the oncologist calls up both the current image data set and the prior image data set. The oncologist displays a transverse slice through the lungs of one of the image sets at the top of the video monitor and a transverse slice of the patient's lungs from the other data set at the bottom of the monitor. The oncologist manually steps through the two data sets independently and manually determines corresponding slices. Often, several thinner slices are fused into a thicker slice.

One of the difficulties resides in the matching of corresponding slices. The matching is both time consuming and subjective.

Moreover, the data from the two data sets may have been generated with different imaging parameters, with a different placement of the patient relative to the center of the scan circle, and the like. The two data sets may have slices of different thickness or skewed at different angles. The images may be shifted relative to the center of the scan circle. There may be differences in the field of view or scale of the images. The lungs may have been imaged at a different pulmonary phase. These and other such factors all contribute to the difficulty of manual image alignment and increase the prospect for subjectivity or human error.

Previously, technique have been developed that use fiducials to align two images. That is, fiducials or imageable markers are affixed to the patient closely adjacent the region of interest so that they are in a fixed relationship. These markers are readily aligned in the two images.

5   However, when the images are taken some duration apart, maybe months, maintaining the fiducials attached to the patient's exterior for that duration is inconvenient. Moreover, fiducials are used less commonly for internal organs in the torso because the patient surface moves in relation to most internal organs with respiration, body position, and the like.

10   Images have also been aligned using anatomical markers. That is, characteristic portions of the body around the region of interest, such as unique locations on the skull or the vertebrae, have been used instead of externally applied fiducials. However, distinct anatomical markers are not readily available for lungs and other organs which can move relative to them. Consequently, most fiducial and anatomical marker

15 alignment techniques have been used in rigid portions of the body, such as the head inside the rigid skull or along the vertebrae.

The present application contemplates a new and improved automated registration technique which overcomes the above-referenced problems and others.

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In accordance with one aspect of the present invention an apparatus for diagnostic imaging is disclosed. A first memory stores a first diagnostic image. A second memory stores a second diagnostic image. A means automatically registers the first and second diagnostic images from the first and second image memories without operator

25 assistance. A means for concurrently displays corresponding slices of the first and second registered diagnostic images. A means concurrently steps the displayed slice to corresponding regions of the first and second images.

In accordance with another aspect of the present invention a method of diagnostic imaging is disclosed. A first and a second diagnostic images are stored. The

30 first and second diagnostic images are automatically registered without operator assistance. Corresponding slices of the first and second registered diagnostic images are concurrently

displayed. The displayed slices are concurrently stepped to corresponding regions of the first and second images.

One advantage of the present invention is that is quick, easy to use, and simple.

5   Another advantage of the present invention is that it is completely automatic.

Another advantage resides in its precision.

Another advantage resides in the coordinated viewing and stepping through the images of both scans in a single action.

10   Yet other advantages reside in the ease of follow-up examinations of the same patient.

Still further advantages and benefits of the present invention will become apparent to those of ordinary skill in the art upon reading and understanding the following detailed description of the preferred embodiments.

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The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating the preferred embodiments and are not be construed as limiting the

20   invention.

FIGURE 1 is a diagrammatic illustration of an apparatus which automatically registers 3D images of a whole body part;

FIGURE 2 is an expanded diagrammatic illustration of a part an apparatus of FIGURE 1 which automatically registers 3D images of a whole body part;

25   FIGURE 3 is a diagrammatic illustration of the affine transform means of FIGURE 1 and associated parts of the apparatus;

FIGURE 4 is an expanded diagrammatic illustration of a part the apparatus of FIGURE 1 which automatically registers 3D images of a whole body part and displays them on the monitor.

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With reference to FIGURE 1, a patient is positioned in a diagnostic imager 10, such as a CT scanner, for a follow-up examination. The generated data is reconstructed by a reconstruction processor 12 and stored in a 3D, volumetric image memory 14. Various image enhancement operations as are known in the art are also performed.

5   Image data from the hospital archive or from another storage medium 16 of the same region of the same patient is retrieved and stored in an archived 3D volumetric image memory 18. Of course, both the current and archive 3D image memories may be parts of a common storage medium. A registering means 20 retrieves the current and archived images and automatically register the two images for a concurrent display on a

10   monitor 22.

With continuing reference to FIGURE 1 and further reference to FIGURE 2, a surface image generating means 24 generates surface images from the current archived images. A segmenting means 26 extracts the important body parts for the registration, then a feature extraction means 28 extracts common features for registration. Looking

15   specifically to lung images, the segmentation includes a thresholding means 30 thresholds the images. More specifically to the lung embodiment, the thresholding means 30 sets the gray scale value of air in the lungs to one extreme value, e.g., black or white, and all tissue in the image to the other. Specifically to lung images, the feature extraction means 28 includes a surface voxel extracting means 32 which extracts the single layer of voxels

20   which lies along the interface between the black and white regions. Preferably, the voxels which represent the tissue surface rather than the air surface are selected. A feature exclusion means 34 removes part of the features of the 3D image that is defective or artifacted, if any. Looking specifically to lung images, portions of the lung closely adjacent to the heart often suffer motion artifacts. To simplify the remaining operations,

25   the feature exclusion means 32 optionally removes a common artifacted region from both image representations. The voxels are stored in feature or surface image memories or memory sections 36, 36'.

A scaling means 40 scales the two surface images in accordance with known differences in scanning parameters. For example, the images are adjusted for

30   differences in the slice thickness of the scans, for the field of view, for magnification differences, and the like. A normalizing means 42 normalizes the two surface images. More specifically to the preferred embodiment, the extreme points along the z-axis of each

image are labeled –1 in one direction and +1 in the other direction. Points in between are labeled proportionately. The same scaling is carried out with respect to the x and y-axes. Different normalization methods are also available, for example, computing the mean or median and standard deviation of the data and setting the central point to the mean or

5   median and the length of one is set to the standard deviation from the mean or median. Of course, other coordinate systems are contemplated. The two scaled and normalized three-dimensional surface images are stored in scaled and normalized volume image memories or memory sections 44, 44'.

With continuing reference to FIGURES 1 and 2 and further reference to

10   FIGURE 3, an affine transform means 50 determines the twelve values of the affine transform that defines the registration error between the current and archived scaled and normalized 3D images. Specifically, the affine transform means 50 determines nine rotational components about three orthogonal axes and three translational components along the three axes. Optionally, a scaling parameter can also be determined.

15   The affine transform means 50 includes a selective or non-uniform random feature or point reducing means 52. That is, with normal CT resolution, the two surface images are still hundreds of thousands of voxels. To reduce the computational load, the selective (based on prior knowledge) point reducing means 52 or a non-uniform random point reducing means 52 preferably selectively (based on prior knowledge) randomly

20   selects a fraction of the points, e.g., 1%, from both images. Because the diagnosing oncologist typically is most concerned with registration along the z- or longitudinal axis, the non-uniformity with which the points are selected is altered to favor points, which influence the z-registration. In the preferred embodiment, a higher percentage of points are selected along the top and bottom axes of the lungs. A matching means 54 matches the

25   non-uniform randomly selected points from the one surface image with a corresponding point in the other surface image. In the preferred embodiment, a K-D tree matching technique or processor 56 is utilized. In each iteration, a non-uniformly random sample of the points from the current image, to be matched to the corresponding point in the other surface image, is taken to be matched to the other set of points from the previous image.

30   For each point in the sample, a matching point is found using the K-D tree. For each matching pair, the coordinates or location of each voxel of the pair and the surface normal are determined. In the matching operation, if more than one candidate point has an equally

good spatial match to the reference point, the point or voxel with the closest normal is selected to generate a set of points and normals which are stored in a point and normal memory means **58**.

A bad pair removal means **60** removes matched pairs of points that fail to

5   meet preselected criteria. In the preferred embodiment, these criteria include a physical separation distance greater than a preselected minimum, badly misaligned normals, and points near to the cut surface, if any. An error estimating means **62** estimates the error between the points. The error estimating means **62** calculates a weighted distance using the differences in x, y, z, and the normals. Each coordinate is assigned with different

10   weight so that the differences in specific parts will be favored over other parts. Looking specifically to lung images, the differences in the z-coordinate have higher weight than the x and y-coordinates, and higher than the normal differences.

With continuing reference to FIGURE 3, an error minimizing or affine registration means **70** finds an affine transform that minimizes the error between the pairs

15   of points. In the preferred embodiment, the error minimizing means **70** uses a Levenberg-Marquardt minimization technique or processor **72**. Using the weighted error estimate and the divergence of the weighted error estimate, the error minimizing means finds **70** a set of affine transformation parameters that gives the minimum of error for the set of sample pairs. Twelve affine transform coordinates and optionally the scaling

20   correction are loaded into a correction transform memory **80**.

With continuing reference to FIGURE 3, a transform processor **82** transforms one of the current and archived scaled and normalized surface images from memories **44, 44'** in accordance with the determined correction transform. The affine transform means **50** repeats the registration technique re-registering the volume images,

25   with one of them subject to the transform, which was predicted, to transform them into registration. This process generates the twelve affine transform coordinates (and optionally scaling) of a correction transform to the first correction transform. An end criteria determining means **84** determines whether the two images have been aligned within acceptable tolerances by monitoring the correction transforms. In the preferred

30   embodiment, the end criteria determining means **84** determines whether the global translation is less than a preselected threshold, whether the change in the correction transform is below a preselected threshold, or whether a preselected number of iterations

have been performed. If any of these criteria are met, a correction transform combining means **86** combines the first correction transform and each of the subsequent correction transforms to provide a single registration transform which is stored in a registration transform memory or buffer **88**.

5   With reference to FIGURE 1 again and further reference to FIGURE 4, a transform operator **90** operates on one of the current and 3D archive images, preferably the archived image to register it with the current 3D volume image. The transformed archived image is stored in a transformed 3D image volume memory **92**.

           An operator, through a keyboard or other input device **100** controls a
10   stepping means **102** which causes a display processor **104** to withdraw and display corresponding slices from the current 3D image memory **14** and the transformed 3D image memory **92** on a monitor **22**. In the preferred embodiment, the transverse slice from the current image memory **14** is displayed on the top half of the screen and the corresponding slice of the transformed memory **92** is displayed on the bottom half of the screen.
15   Preferably, corresponding orthogonal views are displayed adjacent the larger longitudinal slice. The operator input device **100** also controls a slice fusing means **106** that works with the display processor **104** to sum a preselected number of adjacent slices in each of the two images. The operator input means **100** is also connected with a single image slice stepping means **108**, which can control the display processor **104** to step through slices of only one
20   of the two 3D images independently of the other.

           Typically, 3-5 slices are fused together for display on monitor **22**. A global registration algorithm which registers the two three-dimensional volume images within ±2 slices is considered accurate registration due to the fusing of the number of adjacent images.

25   Although described with particular reference to CT scanner imaging, it is to be appreciated that this technique is also applicable to magnetic resonance images, PET images, SPECT images, and other three-dimensional diagnostic images. Moreover, the images being registered may be from mixed modalities. For example, a CT image can be registered using this technique with a PET image. When mixing modalities, care should be
30   taken to assure that the features are defined in both imaging modalities or appropriate adjustment made. Further, although described with particular reference to the lungs, it is to be appreciated that this technique is also applicable to studies of other organs such as the

colon, the liver, and other non-rigid organs. Moreover, this technique is also applicable to rigid portions of the body such as the head.

The invention has been described with reference to the preferred embodiments. Modifications and alterations will occur to others upon a reading and understanding of the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.